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TOXIC LIMITS AND STIMULATION EFFECTS OF SOME SALTS AND POISONS ON WHEAT

CONTRIBUTIONS FROM THE HULL BOTANICAL LABORATORY LXXXVIII

G. H. JENSEN

(WITH THIRTY-FOUR FIGURES)

That the vital activities in plants may be inhibited or accelerated by many mineral salts has long been known in a general way. Hitherto the problem has been attacked mainly from the standpoint of toxic solutions. The work which has taken into consideration the influence of a poison in soil has invariably been done with native soils. In these there are always present a great variety of chemical agents which may individually or collectively react with the introduced poison, and hence no fundamental conclusion can be deduced therefrom. TRUE and OGLEVEE in 1904 (42) showed that the toxicity of a solution was reduced by the introduction of solid insoluble particles. This first suggested the possibility of comparing results obtained from plants grown in solution and in soil. The limited extent to which these authors carried their experiments, however, gave us no more than a suggestion of the possibilities. Previous experimenters, furthermore, have dealt mainly with small parts of the plants, such as the root-tips, determining their limit of endurance.

The present work was undertaken with the purpose of ascertaining the toxic limit for the whole plant in both solution and soil cultures, and thus to make comparisons of the two conditions; to ascertain the effect of pure quartz sand in raising the toxic limit for a given poison upon the same plant; to add to the knowledge of stimulation effects of poisons in solutions; to discover whether these effects were also manifested in soil cultures; and to secure evidence of comparative absorption of different poisons by the same sand.

Historical

The literature dealing with toxic effects on plants divides itself naturally into two classes; first, that which deals with the lower plants; and second, that which deals with the higher plants. The studies of toxic agents on algae and fungi, while they bear upon the present paper only indirectly, frequently furnish valuable data for comparison. Unfortunately the determinations have been made with different ends in view, and have been tabulated in such a way that only here and there can the most general comparisons be made.

LIVINGSTON (**23**, **24**, **25**) has made perhaps the most valuable contribution to this work on the lower plants. His experimentation takes into consideration many toxic salts; determines their killing concentrations as well as the strengths which cause changes in vegetative character of the alga Stigeoclonium. He also attempts (**25**) to correlate the work of previous authors with each other and with his own.

Fungus growth and spore germination as affected by toxic salts in solution was studied by CLARK (**8**). Since it is generally recognized that $Cu(NO_3)_2$ and $CuSO_4$ have very nearly the same if not identical toxic limits for a given plant (**25**, p. 18), it is interesting to note from this table:

Aspergillus in $Cu(NO_3)_2$ dies in $25n/100$
Sterigmatocystis in $CuSO_4$ dies in $125n/1000$
Penicillium in $Cu(NO_3)_2$ dies in $n/1$
Oedocephalum in $Cu(NO_3)_2$ dies in $156n/10000$
Botrytis in $Cu(NO_3)_2$ dies in $313n/10000$

Thus Penicillium will endure approximately four times as much copper as Aspergillus; eight times as much as Sterigmatocystis; thirty times as much as Botrytis; and sixty times as much as Oedocephalum.

According to STEVENS (**39**) many metallic salts affect spore production in fungi. Among these $Cu(NO_3)_2$ and $CuSO_4$ inhibit spore formation at a lower concentration than any of the others tried by him, the response occurring at $n/100$ in Penicillium.

The response of acceleration of growth of plants as caused by toxic elements in solutions has been studied in conjunction with the response of death. There seems to be a general agreement among authors that zinc is the most active stimulating agent to vegetative growth. Yet the concentrations at which $ZnSO_4$ are said to produce most marked acceleration are far from agreeing. Thus, RICHARDS

(34) says that 6*n*/ to 12*n*/100000 and ONO (32) that 25*n*/ to 200*n*/100000 produce the greatest dry weight of mycelium in Aspergillus. RICHTER (35) did not get acceleration of growth with $CuSO_4$ nor with AgCl.

Within the past decade considerable work on seedlings of higher plants dealing with their relation to toxic agents has appeared. In nearly all cases this work has been limited to the effect of the toxic agent upon some particular part or organ, and has taken no account of the endurance of the plant as a whole for the poison. Thus KAHLENBERG and TRUE (21) record a large number of experiments upon white lupine radicles. They determined for this organ the fatal dose of various organic and inorganic substances. They found that H and OH ions are the deleterious agents. This work establishes the limit of endurance of the root-tip of white lupine only, and not, as COUPIN (10) points out, the endurance of the whole plant. In the same fashion HEALD (19) worked with seedlings of Zea, Pisum, and Cucurbita. He found that in KCN, $K_4Fe(CN)_6$, and $K_3Fe(CN)_6$ the electro-negative ion or anion was toxic. In all others it was the electro-positive ion or cation. PLOWMAN (33) dealt with the question from the standpoint of electricity and magnetism. From the fact that plants in the soil in the vicinity of the positive pole were stimulated, while those at the negative pole were not, he concluded that ionization of the soil solutions bore directly upon growth.

That roots may accommodate themselves to gradually increasing concentrations of toxic substances (38) has long been known, as has also the fact that the power of absorbing water containing salt is lost more and more by roots (36) the longer they are in contact with it. GUTHRIE and HELMS (16) worked with wheat, maize, barley, and rye in pot cultures, using native soil. Their idea was to determine the endurance of some farm crops for certain injurious substances frequently present in soils. Table A, made from their data, shows the per cent. of poison which prevents germination.

From these results it would seem that seeds will successfully germinate in somewhat higher concentration than that in which the plants will later grow. TRUE and OGLEVEE (42) found that various insoluble substances, potato starch, paraffin, coal, glass, filter paper,

TABLE A

Reagent		Wheat	Maize	Barley	Rye
NaCl	Germination prevented by .	0.20%	0.50%	0.25%	0.40%
	Growth prevented by	0.20	0.25	0.20	0.20
Na_2CO_3	Germination prevented by .	0.5–1.0	0.50	0.60	0.50
	Growth prevented by	0.40	0.25	0.40	0.40
NH_4CNS	Germination prevented by. .	0.015	0.02+	....	....
	Growth prevented by	0.005	0.02+	....	....
$NaClO_3$	Germination prevented by. .	0.053	0.006+	0.007	0.006
	Growth prevented by.......	0.003	0.004	0.006	0.004
$AsO(OH)_3$	Germination prevented by. .	0.5+	0.80+	0.60*	0.40
	Growth prevented by	0.10	0.60	0.10	0.30

* Not effective.

when added in finely divided particles to toxic solutions, markedly reduced the toxicity. They account for the reduction as being due to adsorption of poisonous particles by the substances introduced.

In a recent paper LIVINGSTON (27) goes very fully into the physiological properties of a remarkably sterile soil, known locally as Tacoma Park soil. He concludes that some reagents, such as pyrogallol, calcium carbonate, and tannic acid, may act chemically upon the toxic bodies of the soil, while ferric hydrate and carbon black are merely absorbents of the same.

KANDA (22) worked with solution cultures, and pot cultures of native soil. The latter were watered with poisonous solutions of the same salts from which his solution cultures were made. He was the first to show that $ZnSO_4$ is an active stimulant to higher plants. He did not observe stimulation with solution cultures of $CuSO_4$, but soil cultures gave quite marked stimulation. The results that he records for Pisum and *Vicia Faba* in this respect agree with my own on wheat.

HARTER (18) exposed wheat roots for twenty four hours to toxic solutions. He found that varieties of wheat from arid regions of Russia, where the soil is alkaline, are more resistant than are those grown in more humid regions. The reagents used by HARTER were sodium carbonate, bicarbonate, sulfate, and chlorid; and magnesium sulfate and chlorid. His work therefore naturally suggests that relative toxicity of salts must be learned by experimenting upon a single variety or strain; and to overcome errors due to individual variation many plants must be used.

That it is next to impossible to coordinate data from different authors is evident from Table B, taken from CAMERON and BREAZEALE (7). For, as they say, the toxicity needed "to kill a seedling or disorganize an entire radicle varies widely from that required to completely hinder any growth, or that which will permit some elongation."

TABLE B

SOLUTE	TOXIC LIMITS FOR	
	Whole seedling	Tip of radicle
H_2SO_4	n/9	n/15000
HCl	n/10	n/18000
HNO_3	n/7	n/15000
Acetic acid	n/13	n/20000
Oxalic acid	n/1	n/15000
Succinic acid	n/1	n/20000
Calcium chlorid	n/3	n/4
Calcium nitrate	n/3	n/5

DANDENO (11) worked with pea, lupine, and corn. He found that the toxicity of poisonous solutions is reduced by the presence of pure quartz sand. Thus in $CuSO_4$, seedlings will grow in *n*/4096 when sand is present, while they will stand only *n*/32768 when no sand is present. He also found that the effect is related to the size of the particles, more growth being permitted with fine sand than with coarse sand. My own experimentation with H_2SO_4 shows similar results. Thus with number 5/0, the finest quartz, growth was inhibited at 7*n*/100 to 6*n*/100; in number 2/0, the next coarser grade, at 5*n*/100 to 4*n*/100; in number 2, a rather coarse sand, at 4*n*/100 to 2*n*/100; in number 4, a very coarse grade, at 2*n*/100 to 9*n*/1000; in solution (H_2O), at 8*n*/1000 to 6*n*/1000. Which goes to show that the coarser the sand the less the same amount of solution is reduced in toxicity. Or, in other words, the coarser the sand, the nearer does the culture approach to solution media. DANDENO does not think with TRUE that the growth of lateral roots in solutions that killed the primary radicle is due to "accommodation," but that the first growth of the radicle has reduced the toxicity to such an extent that the later roots can endure it. That the quantity of toxic agent has considerable to do with the effect upon growth, he shows by a series of eight cultures, successively planted in different quantities of poison. Thus, seedlings lived in 1^{cc} HCl $n/1024$ for the first day, and not in quantities more than 1^{cc}; while at the end of the eight successive plantings in the same solutions seedlings were able to survive on the eighth day in 12^{cc} HCl $n/1024$; hence definitely proving that each successive planting reduces the toxicity of the solution. He says this is due to exudations of substances from the root. These same exudations furnish organic material for the growth of fungi, which (as was also my experience) are very apt to make their appearance in a few days.

BREAZEALE (5) made soil extracts of unproductive soils. To these extracts, filtered through a Chamberland filter he added various solids, such as ferric hydrate, calcium nitrate, calcium carbonate, carbon black, and fine quartz flour. He found that ferric hydrate and carbon black produce abnormal lengthening of roots, while the quartz flour does not. In his experiments on maize with sulfuric acid $n/2750$ to $n/3250$ prevented growth. Quartz flour did not change the apparent death limit. Clear sand, bits of filter paper, and paraffin shavings showed similar results with H_2SO_4. His results thus far, therefore, are diametrically opposed to those of TRUE and OGELVEE. With $CuSO_4$ on the other hand, carbon black reduced the toxic effect. My own results, in so far as quartz flour is concerned, showed almost invariably that it reduces toxicity. The only exception is in phenol and alcohol.

Materials

Ground quartz, or quartz flour, of the grade commercially known as 5/0, which is a very fine powder, was the soil medium used. Wire baskets 8×8^{cm}, paraffined and covered as described by LIVINGSTON (27), formed the pots for the soil cultures.

For the solution series, 500^{cc} bottles with a wide mouth were generally used. A smaller dark bottle, of 70^{cc} capacity, was also used, but did not give as uniformly good results as the larger bottle.

The wheat used throughout these experiments was obtained from the Bureau of Soils, Washington, D. C., through the kindness of Dr. LIVINGSTON. It is the variety known as *Chul*, grown in Utah, and was brought from central Turkestan by Dr. ERNST BESSEY.

All salts used for nutrient media, as well as those used as poisons, were Kahlbaum's C. P. grade.

The ordinary distilled water of the laboratory was re-distilled in glass flasks. From this redistilled water all solutions were made.

Methods

Preliminary experiments for the determination of the optimum water content of the quartz were first carried out with redistilled water and with nutrient solution. It was found that 12 to 15 per cent. by weight of water was best.

The wheat seeds were germinated in sphagnum and in quartz. It was found that the sphagnum was more satisfactory, because foreign particles could be more easily removed from the roots at transplanting. Transplanting was done when plants had attained a maximum height of 3^{cm}.

Three hundred and thirty-six grams of quartz were weighed out for each culture basket. This was mixed with 42^{cc} of solution, thus making 12.5 per cent. of moisture content. This damp soil was then packed in the basket, and with the culture series completed, all were planted with plants as nearly alike as possible. The plants (five in each pot) stood in a straight line and protruded through a slit in the paraffined paper cover. The latter was then sealed to the sides of the pot with melted paraffin. The pot was labeled with the strength of solution it contained and the weight. The slit through which the plants protruded was loosely plugged with ordinary cotton, so that the loss of weight was practically reduced to the transpiration by the plants. After two or three days the pots were put on the scale-pan, the original registered weight was placed on the opposite pan, and a balance obtained by adding to each some solution of its own strength from a pipette. Thus the weight was again made what it was at the time of planting. This was done as often as needed; at first each two or three days; afterward, as plants got larger, every day. In this way the amount of water was never more than 12.5 per cent. and probably never less than 10 per cent. The amounts added were recorded, and their sum constitutes the total transpiration for a pot as recorded in the tables. At the end of the experiment, usually in 15 to 30 days, the longest sprout of each plant was measured, the recorded length being taken from the surface of the pot to the tip of the leaf. The average of these lengths for a given pot constitutes the average length of sprout recorded for that culture. The plants were then cut off close to the surface, cut into short pieces into a crucible, and the green weight recorded. After drying in a Bausch and Lomb oven for 5 to 7 days at 100–110° C. the dry weight was recorded.

Corks fitting the bottles used for solution cultures were perforated with a small cork-borer so that six plants could be grown in each of the larger bottles. The corks were then boiled for several hours, with numerous changes of water, in order to remove any possible injurious ingredients. After being dried, they were boiled in paraffin, to insure an upper surface that could not be wetted. The wheat plants were now inserted through the perforations, so that the seed and roots were below the lower surface of the cork and in the solution. The holes were loosely plugged with ordinary cotton to fasten the plants and to prevent evaporation. Bottles were weighed from time to time and solution replaced from a pipette, record being kept of the amount lost by transpiration from each bottle. The length of the sprout was measured from the upper surface of the cork to the tip of the longest leaf of each plant as in the case of the soil cultures. The green and dry weight of the whole plant from the solution cultures was always taken; while in the soil cultures only the aerial portion is available for comparison.

Fungus contamination in solution cultures was practically overcome by sterilizing seeds in a 2 per cent. $CuSO_4$ solution for three-fourths of an hour; washing afterwards in sterilized water; planting in sterilized sphagnum, and transplanting in a sterile chamber into sterilized solutions. The sterile chamber was a box $100 \times 50 \times 50^{cm}$, with a glass cover and a glass window in front. Rubber-cloth sleeves which fit snugly around the wrists of the operator were provided. The chamber was thoroughly sprayed with $CuSO_4$ before using.

The series in solution and in soil were grown at the same time, under the same conditions of light, heat, and other external factors.

Experimentation

Responses to toxic salts are of two kinds: (*a*) acceleration and (*b*) retardation of growth which progresses as the concentration increases until the death point is reached. By the *death point* is not meant that concentration at which all elongation of root or sprout from the very first is inhibited, but that which kills the plant when the stored food of the seed has been exhausted. Thus it was found that after 5 to 10 days plants which at first grew well lost their vigor and turned yellow.

The criteria used for comparing the effect of the substances tested are: first, the total transpiration from each pot or culture; second, the average length of the sprout; third, the green weight; fourth, the dry weight of plants in a pot.

The curves are as follows: The unbroken line is the average length of the sprout; the broken line is the total transpiration; the dotted line is the green weight; and the dot-and-dash line represents the curve of the dry weight.

COPPER SULFATE

In the solution series plants all die in *n*/1000 strength and do very badly in 5*n*/100000. There is no indication of any stimulation, as the control in distilled water has grown more than any other set. In the series where 50^{gm} of 5/0 quartz sand is added to an equal weight of solution, that is, where the quartz stood half way up the column of liquid, we find the wheat growing in *n*/1000 and not altogether dead in 4*n*/1000. The toxicity has evidently been reduced. In the series where 90^{gm} quartz to 25^{gm} solution is used, i. e., the solution stands about a centimeter above the surface of the sand, the toxic effect has been still further reduced. The killing point now lies between 4*n*/1000 and 8*n*/1000. In the soil series, i. e., where 12.5 per cent. of solution is present, the death point lies between *n*/100 and 3*n*/100. It will be evident, therefore, that the greater the ratio of quartz to the poisonous solution, provided this does not exceed the optimum water content for growth, the less the toxic effect of the copper sulfate. *Fig. 1* represents a $CuSO_4$ series in soil six days after planting. The series is close, running from left to right *n*/10, 9*n*/100, 8*n*/100, 7*n*/100, 6*n*/100, 5*n*/100, 4*n*/100, 3*n*/100, 2*n*/100, *n*/100, 9*n*/1000, 8*n*/1000, 7*n*/1000, 6*n*/1000, 5*n*/1000, 4*n*/1000, 3*n*/1000, 2*n*/1000, *n*/1000, *n*/2500, *n*/5000, *n*/7500, *n*/10000, control. It shows that up to 3*n*/100 all elongation is inhibited. Beyond this point it shows a rather uniform increase of growth, as the solution strength, with which the soil is moistened, decreases. Normal growth is reached at about 2*n*/1000. Between the point at which no growth takes place and where normal growth may be attained, we will, for convenience, call the tension line or line of stress. It means that region of concentration in which a struggle for life is apparent. In *fig. 2*, which is a photograph of the same series 12 days old arranged in opposite direction, it will be noted that *n*/1000 to *n*/2500 has grown more than the control. Also that *n*/100 and 9*n*/1000, which were growing in *fig. 1*, are now dead. It thus shows that during the first six days the seedling was able to endure a higher concentration than afterward; and further, that acceleration does not occur until after the reserve food of the seed has been exhausted.

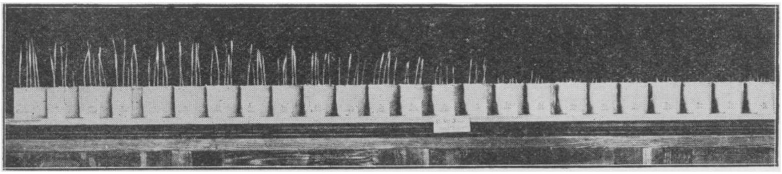

FIG. 1.—Copper sulfate series in soil. Aug. 24–30. 1905.

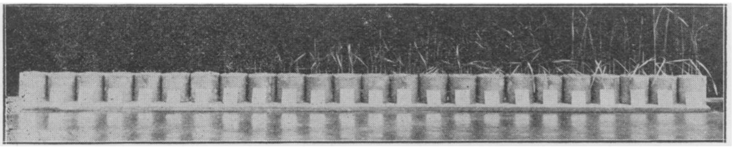

FIG. 2.—Copper sulfate series in soil. Aug. 24–Sept. 26. 1905.

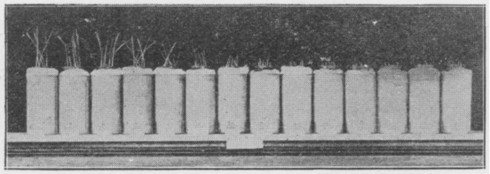

FIG. 3.—Copper sulfate series in solution. Aug. 22–30. 1905.

The solution series represented in *fig. 3* had concentrations from left to right as follows: 9*n*/1000, 8*n*/1000, 7*n*/1000, 6*n*/1000, 5*n*/1000, 4*n*/1000, 3*n*/1000, 2*n*/1000, *n*/1000, *n*/2500, *n*/5000, *n*/7500, *n*/10000, control. In this series no elongation has taken place in concentrations above $3n/1000$; the curve of increase of growth rapidly rises as the concentration decreases, and much more rapidly than it does in soil. There is no indication of any acceleration in the photographed series, nor was any acceleration found in $CuSO_4$ solution culture, although the experiment was twice repeated with dilutions as low as $n/100000$.

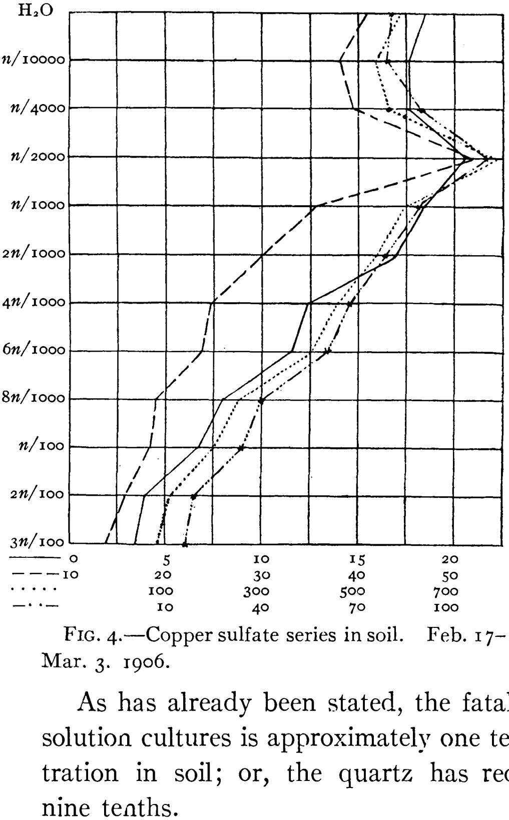

FIG. 4.—Copper sulfate series in soil. Feb. 17–Mar. 3. 1906.

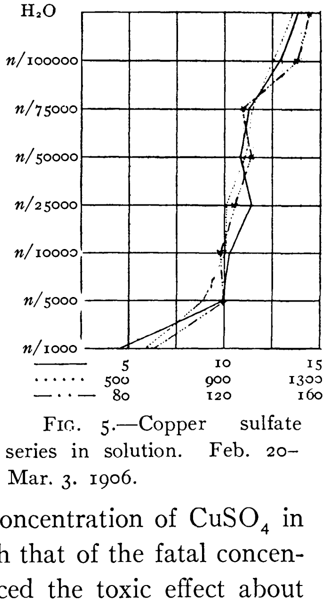

FIG. 5.—Copper sulfate series in solution. Feb. 20–Mar. 3. 1906.

As has already been stated, the fatal concentration of $CuSO_4$ in solution cultures is approximately one tenth that of the fatal concentration in soil; or, the quartz has reduced the toxic effect about nine tenths.

Tables I, II, III follow and curves (*figs. 4, 5*) precede. From these it will be seen that the transpiration, the length of sprout, and the green and dry weights vary quite uniformly.

TABLE I

$CuSO_4$ SERIES IN SOIL; 12.5% MOISTURE. FEBRUARY 17–MARCH 3. 1906

	H_2O	$\frac{n}{10000}$	$\frac{n}{4000}$	$\frac{n}{2000}$	$\frac{n}{1000}$	$\frac{2n}{1000}$	$\frac{4n}{1000}$	$\frac{6n}{1000}$	$\frac{8n}{1000}$	$\frac{n}{100}$	$\frac{2n}{100}$	$\frac{3n}{100}$
Av. length of sprout, cm...	18.96	17.76	17.70	20.68	18.44	16.96	11.98	11.56	8.02	7.26	4.10	3.42
Total transpiration, gm....	41.6	37.9	39.4	52.0	35.4	30.2	24.8	23.8	18.5	18.5	15.9	13.9
Total green weight, mg....	590	535	563	782	597	539	450	400	250	200	115	92
Total dry weight, mg......	80	78	88	112	90	79	68	62	40	35	18	17

TABLE II

$CuSO_4$ SERIES. EXPERIMENTS TO SHOW THE EFFECT OF QUARTZ IN SOLUTION

	H_2O	$\frac{n}{100000}$	$\frac{n}{1000}$	$\frac{4n}{1000}$	$\frac{8n}{1000}$	$\frac{n}{100}$	$\frac{2n}{100}$
50gm quartz to 50cc solution							
Av. length of sprout, cm	15.35	11.42	6.57	3.60	3.12		
90gm quartz to 25cc solution							
Av. length of sprout, cm	14.85	14.72	11.65	7.2	4.8	3.4	2.2

TABLE III

$CuSO_4$ SERIES IN SOLUTION; 500cc BOTTLES. FEBRUARY 20–MARCH 3. 1906

	H_2O	$\frac{n}{100000}$	$\frac{n}{75000}$	$\frac{n}{50000}$	$\frac{n}{25000}$	$\frac{n}{10000}$	$\frac{n}{5000}$	$\frac{n}{1000}$
Average length of sprout, cm	13.87	12.95	11.33	10.98	11.41	10.25	9.58	4.06
Total green weight, mg	1296	1123	980	982	915	931	825	575
Total dry weight, mg	155	150	128	130	123	118	120	90

LEAD NITRATE

In the preliminary experiment with lead nitrate from which *fig. 6* is taken, the series runs from right to left as follows: 8*n*/100, 7*n*/100, 6*n*/100, 5*n*/100, 4*n*/100, 3*n*/100, 2*n*/100, *n*/100, 9*n*/1000, 8*n*/1000, 7*n*/1000, 6*n*/1000, 5*n*/1000, 4*n*/1000, 3*n*/1000, 2*n*/1000, *n*/1000, *n*/2500, *n*/5000, *n*/7500, *n*/10000, control.

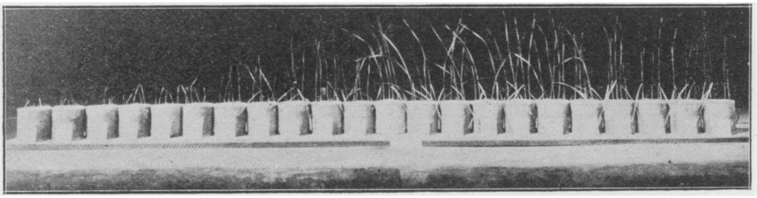

FIG. 6.—Lead nitrate series in soil. Sept. 2–14. 1905.

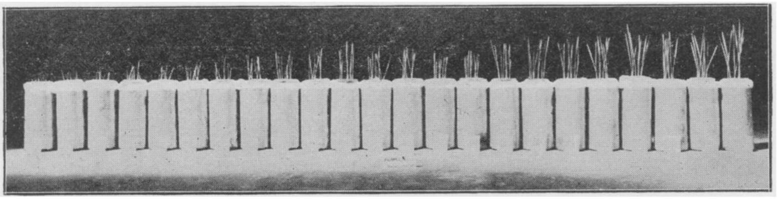

FIG. 7.—Lead nitrate series in solution. Sept. 10–14. 1905.

The same concentrations, arranged in the same order, hold for the series in solution, *fig. 7*.

The experiment with soil was thrice repeated, and the results of each experiment are indicated in the curves, *figs. 8, 9, 10*. The separate tables are not given, but Table IV embodies the averages obtained from the three, as does also the curve, *fig. 11*. The greatest stimulation, at 6*n*/1000, falls off in concentrations both above and below this. If the control be considered "normal growth," it will be evident by reading *fig. 11* that all concentrations from *n*/100 to *n*/10000 inclusive cause acceleration. Death occurs at 4*n*/100, a very slight elongation is shown at 3*n*/100, and a little more at 2*n*/100. Between 2*n*/100 and *n*/100 a rapid increase in growth rate occurs. In comparison with $CuSO_4$, therefore, acceleration may be caused by concentrations very near the fatal concentration.

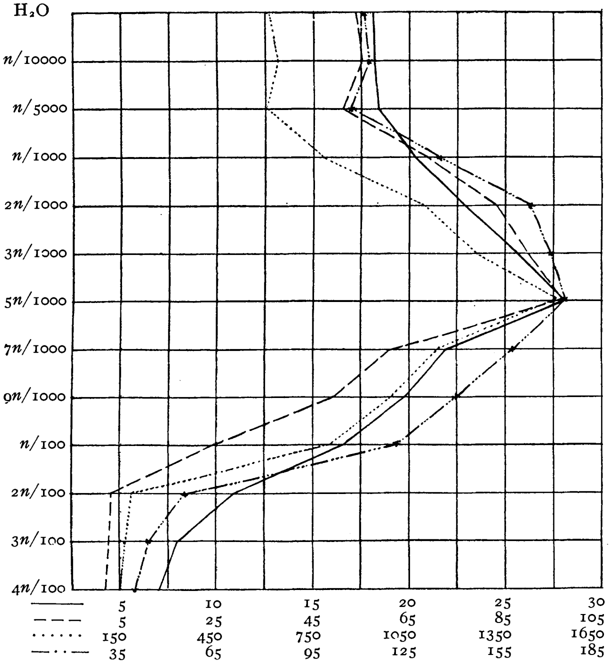

FIG. 8.—Lead nitrate series in soil. Nov. 19–Dec. 20. 1905.

In the solution series of lead nitrate, Table V and *fig. 12*, the death point lies at 4*n*/100 to 2*n*/100, approximately at the same concentration as in soil. Hence there is little if any indication of reduction of toxic effect, in so far as the death point is concerned.

Acceleration is not evident in nearly as marked a degree as in soil, however, and is not evident in nearly as concentrated solutions. Hence, while no appreciable change in the killing strength is made evident by the presence of quartz, a very marked change has occurred with respect to acceleration. In solution acceleration occurs at *n*/5000 to *n*/10000.

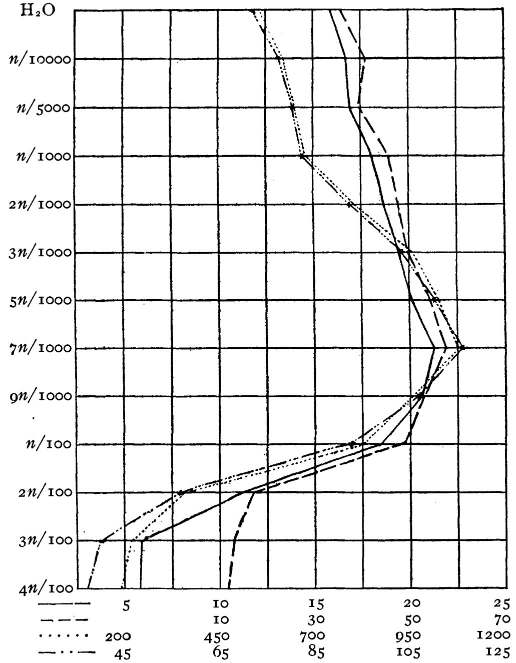

FIG. 9.—Lead nitrate series in soil. Feb. 2–19. 1906.

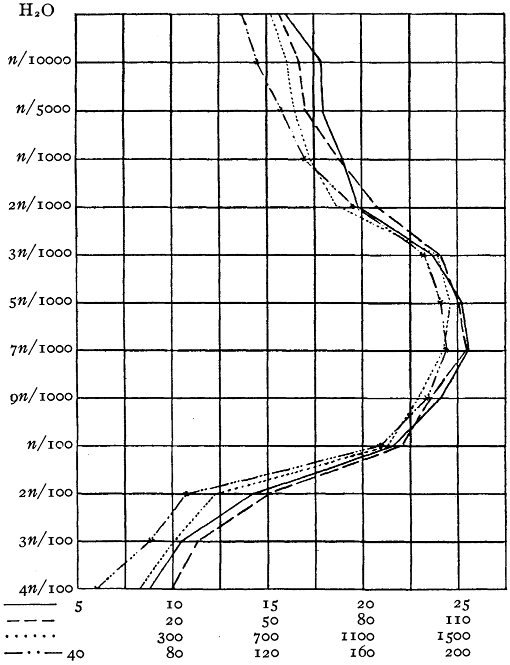

FIG. 10.—Lead nitrate series in soil. Apr. 10–27. 1906.

TABLE IV

$Pb(NO_3)_2$ SERIES IN SOIL. AVERAGE OF THREE EXPERIMENTS

	H_2O	$\frac{n}{10000}$	$\frac{n}{5000}$	$\frac{n}{1000}$	$\frac{2n}{1000}$	$\frac{3n}{1000}$	$\frac{5n}{1000}$	$\frac{7n}{1000}$	$\frac{9n}{1000}$	$\frac{n}{100}$	$\frac{2n}{100}$	$\frac{3n}{100}$	$\frac{4n}{100}$
Av. length of sprout, cm.	16.61	17.87	17.91	19.46	20.26	21.15	21.54	23.18	21.61	19.34	12.21	8.31	5.77
Total transpiration, gm.	48.90	52.77	55.83	62.57	72.30	71.40	81.80	87.60	65.06	55.60	17.47	14.33	11.30
Total green weight, mg.	628	682	688	776	950	1100	1125	1173	1069	984	336	295	180
Total dry weight, mg...	97	105	110	117	134	135	150	149	140	130	63	47	43

TABLE V

$Pb(NO_3)_2$ SERIES IN SOLUTION. FEBRUARY 2–17. 1906

	H_2O	$\frac{n}{10000}$	$\frac{n}{5000}$	$\frac{n}{1000}$	$\frac{2n}{1000}$	$\frac{4n}{1000}$	$\frac{6n}{1000}$	$\frac{8n}{1000}$	$\frac{n}{100}$	$\frac{2n}{100}$	$\frac{4n}{100}$
Av. length of sprout, cm.	10.5	12.47	11.35	10.2	10.4	9.75	8.15	8.9	8.92	7.3	5.3
Total transpiration, gm..	11.6	12.30	12.50	11.6	11.1	9.90	9.20	9.7	9.7	7.9	7.0
Total green weight, mg..	670	725	640	620	585	540	523	520	476	445	408
Total dry weight, mg....	85	95	84	80	79	77	78	75	73	72	70

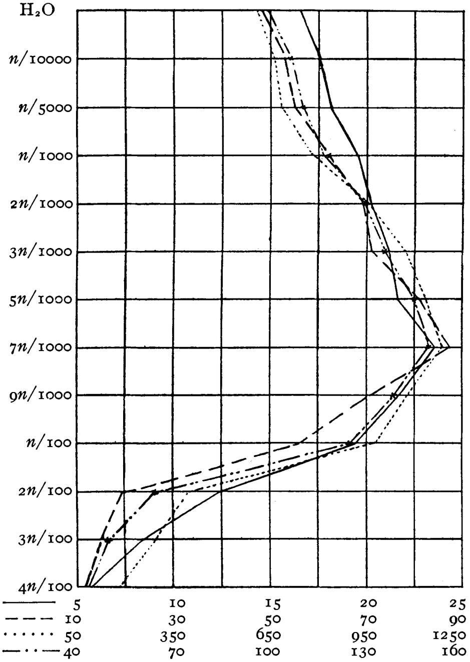

FIG. 11.—Lead nitrate. Average of three experiments.

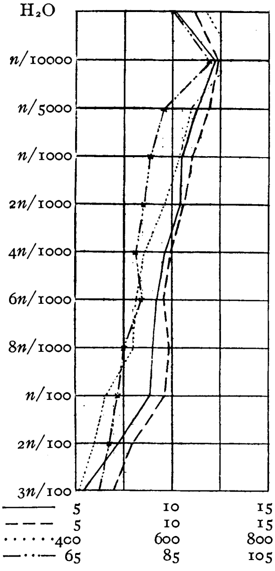

FIG. 12.—Lead nitrate series in solution. Feb. 2–17. 1906.

SILVER NITRATE

The experiments with silver nitrate were repeated three times. *Figs. 14, 15* are taken from the first one. The results of the different tests correspond quite closely, hence only the averages are here given in Table VI and graphically in *fig. 13*.

The toxic limit is about the same concentration (4*n*/100 to 3*n*/100) as with lead nitrate; there is very little toxic effect shown above 9*n*/1000; the region of acceleration is at 2*n*/1000.

TABLE VI

$AgNO_3$ SERIES IN SOIL. AVERAGE OF THREE EXPERIMENTS

	H_2O	$\frac{n}{10000}$	$\frac{n}{5000}$	$\frac{2n}{1000}$	$\frac{3n}{1000}$	$\frac{5n}{1000}$	$\frac{6n}{1000}$	$\frac{8n}{1000}$	$\frac{9n}{1000}$	$\frac{n}{100}$	$\frac{2n}{100}$	$\frac{3n}{100}$	$\frac{4n}{100}$
Av. length of sprout, cm.	20.64	21.50	22.48	22.58	21.44	20.06	19.68	19.74	17.82	16.42	15.50	13.22	2.55
Total transpiration, gm..	61.4	62.2	66.9	67.9	65.6	57.6	54.9	53.2	51.1	42.1	36.1	30.5	16.1
Total green weight, mg..	845	840	897	934	864	822	800	790	779	713	350	220	35
Total dry weight, mg.	130	136	139	150	147	144	137	131	130	122	110	97	15

In *fig. 14* is represented a series of 23 cultures six days old, in quartz, running from left to right *n*/10, 9*n*/100, 8*n*/100, etc., as in the case of $CuSO_4$ and $Pb(NO_3)_2$. A small amount of elongation has taken place in 4*n*/100, considerable in 3*n*/100, and in 2*n*/100 the growth is about normal. In *fig. 15* the same series is 12 days old.

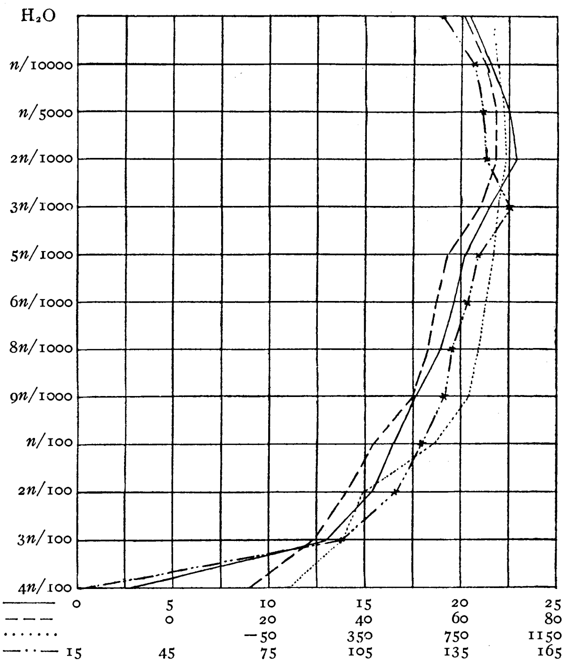

FIG. 13.—Silver nitrate series in soil. Average of results.

Here 4*n*/100 and 3*n*/100 are dead, while 2*n*/100 has maintained its rate of growth almost equal with the control. The death limit is therefore very clearly pointed out. On the other hand, acceleration is very vague.

The solution series (*fig. 16*) represents a series beginning at the left with 7*n*/1000, 6*n*/1000, 5*n*/1000, etc., as in *figs. 14, 15*. Here all elongation is inhibited in concentrations up to 4*n*/100, and from 4*n*/100 to *n*/1000 there is a slight elongation, with considerable broadening of the leaves. In concentrations from *n*/1000 to *n*/10000 elongation increases. That actual acceleration might be definitely shown, however, another series with solutions more dilute was grown. In this the series runs as follows: *n*/10000, *n*/25000, *n*/50000, *n*/100000, control. A definite region of acceleration is shown in *fig. 17*, which represents the results obtained with these very dilute solutions. See also Table VII.

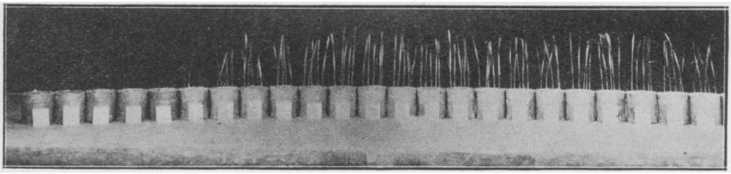

FIG. 14.—Silver nitrate series in soil. Sept. 10–15. 1905.

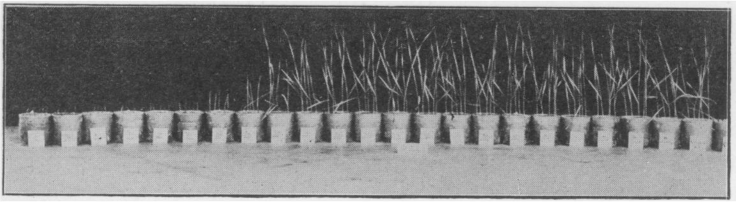

FIG. 15.—Silver nitrate series in solution. Sept. 10–22. 1905.

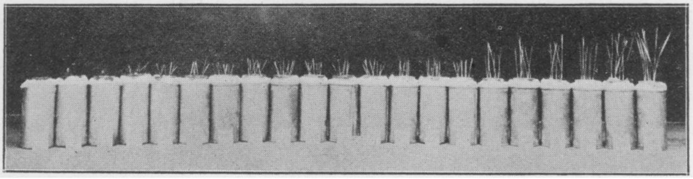

FIG. 16.—Silver nitrate series in solution. Sept. 10–15. 1905.

TABLE VII

$AgNO_3$ SERIES IN SOLUTION. FEBRUARY 19–MARCH 4. 1906

	H_2O	$\frac{n}{100000}$	$\frac{n}{75000}$	$\frac{n}{50000}$	$\frac{n}{25000}$	$\frac{n}{10000}$
Av. length of sprout, cm.......	9.25	9.51	10.76	11.16	7.33	5.73
Total green weight, mg........	870	899	965	981	887	572
Total dry weight, mg.........	109	112	117	121	90	84

It is evident that the quartz has a very marked effect in reducing the toxic effect of the silver. For example, the death point in soil is at a concentration of $3n/100$ to $2n/100$; in solution the death point is at $n/10000$; this, in comparison with other poisons used, is a considerable difference.

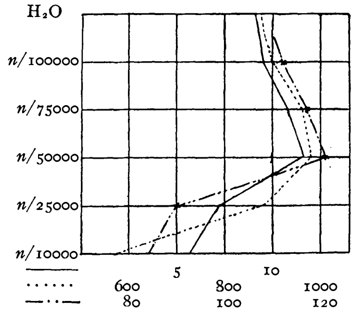

FIG. 17.—Silver nitrate series in solution. Feb. 19–Mar. 4. 1906.

Working on the assumption that the great difference in toxicity between soil and water cultures was due to absorption of the poison by the sand particles, a series of cultures, all containing the same strength of solution at first, but a varying quantity of quartz, was set up. The set consisted of seven 500^{cc} bottles. The solution strength used was $5n/1000$. The amounts of solution and quartz sand in each bottle were as follows:

Number	1	2	3	4	5	6	7
Solution	150^{cc}	208^{cc}	310^{cc}	365^{cc}	410^{cc}	455^{cc}	500^{cc}
5/0 quartz	625^{gm}	625^{gm}	500^{gm}	375^{gm}	250^{gm}	125^{gm}	25^{gm}

That is, we have in 1 about 19 per cent. solution to 81 per cent. sand; in 2, 25 per cent. to 75 per cent, sand; in 3, 38 per cent. to 62 per cent. sand or supersaturated; in 4 the solution stands about 2^{cm} above the sand; in 7 the sand stands less than 1^{cm} from the bottom; 5 and 6 are intermediate between 4 and 7. The experiment lasted ten days and the results obtained are as follows:

TABLE VIII

TO SHOW EFFECT OF VARYING AMOUNTS OF QUARTZ IN POISONED SOLUTION

No.	Length of sprout.						Average	Remarks
1	1.5	1.2	1.6	0.8	1.4	0.7	1.2	Roots all dead
2	2.5	2.3	2.2	1.6	1.3	1.0	1.8	Roots all dead
3	3.1	3.2	3.2	1.5	2.6	0.7	2.4	Roots dead and very slightly elongated
4	2.5	2.2	2.6	2.6	2.5	3.3	2.6	Roots had penetrated into liquid but were dead
5	3.0	3.7	3.0	2.5	2.9	2.1	2.86	Roots alive, plants struggling
6	8.8	11.6	10.7	9.2	10.4	11.7	10.4	Plants healthy
7	11.7	10.4	11.2	10.1	9.0	10.5	10.5	Plants healthy

The data show an increasing growth with the increase in amount of sand present. This agrees with TRUE and OGLEVEE'S results. At the end of the experiment the solutions in which the plants had grown were carefully titrated with NaCl, giving the following results:

1. Sand about 1^{cm} high, considerable precipitate.
2. Sand about 3.5^{cm} high, some precipitate.
3. Sand about 6^{cm} high, minute trace.
4. Sand about 8^{cm} high, no trace.
5. Sand about 10^{cm} high, no trace.
6. Sand filled bottle, no trace.
7. Sand filled bottle, no trace.

I endeavored to make quantitative determinations, and thus definitely to settle the absorptive power of a given quantity of quartz, and at the same time the relation of the amount of silver to length of plant grown therein. My attempts, however, were unsuccessful.

The solutions from the above experiment were filtered free from sand, and again used for solution culture in small black bottles (70^{cc}) with the following results:

1. Gave no elongation of root or stem. Roots and base of stem dark brown.
2. Stems slightly elongated. Leaves very much etiolated. Roots long and healthy.
3. About like 2.
4. Stems healthy. Leaves green. Roots white, long and healthy. Av. size 7.9^{cm}.
5. Same as in 4. Average length of sprout 8.3^{cm}.
6. Soil extract from previous experiment insufficient for this test.
7. Soil extract from previous experiment insufficient for this test.

In order to test still further the absorptive power of the quartz, a series of cultures, each containing the same quantity of sand and solution, were set up. The difference here was that each culture had a different strength of solution. The quantity of sand used for each was 270 grams, and of solution 400 grams. The concentrations are indicated in table IX.

TABLE IX

EXPERIMENT TO SHOW EFFECT OF QUARTZ UPON DIFFERENT CONCENTRATIONS OF $AgNO_3$

	$\frac{5n}{100}$	$\frac{n}{100}$	$\frac{n}{500}$	$\frac{n}{2500}$	$\frac{n}{12500}$	$\frac{n}{62500}$
Average length of sprout, cm...	3.1*	5.3	8.5	9.4	10.2	13.9
Total green weight, mg........	255	230	388	500	545	765
Total dry weight, mg..........	67	47	60	80	82	117

*Dead.

In comparison with this, a set of the same concentrations of solution, in the same kind of bottle (500^{cc}) but containing no sand, were set up. The plants were grown the same length of time, in the same external conditions, and gave the following results: In *n*/62500 and *n*/12500 good growth was obtained, but in all solutions of greater concentration plants all died. It is quite evident, therefore, that the quartz added reduced the toxic effect of *n*/100, *n*/500, and *n*/2500 to something less than *n*/2500; perhaps, as is shown by the first series of solution cultures, to something less than *n*/10000. This conclusion is also drawn from the fact that roots, stems, and leaves were as vigorous in *n*/2500+quartz as were the plants in *n*/12500 solution alone.

After filtering away sand the solutions were again used in solution cultures in small black bottles (70^{cc}) with the following results:

	$\frac{5n}{100}$	$\frac{n}{100}$	$\frac{n}{500}$	$\frac{n}{2500}$	$\frac{n}{12500}$	$\frac{n}{62500}$
Average length of sprout, cm...	0.0	4.5	10.9	12.2	11.3	11.3

This shows that is it not necessarily the presence of the quartz *at the time of growth* which reduces the toxicity, but that quartz having stood in the solution has taken out some of the poison. Here, as in a previous experiment, the titration failed to yield quantitative results. The conclusion, however, is inevitable that quartz does remove considerable quantities of silver nitrate from solution, or at least renders it inert.

ZINC SULFATE

The series shown in *figs. 18, 19* has the same arrangement and concentration of $ZnSO_4$ as that shown and explained in *figs. 15, 16* for $AgNO_3$.

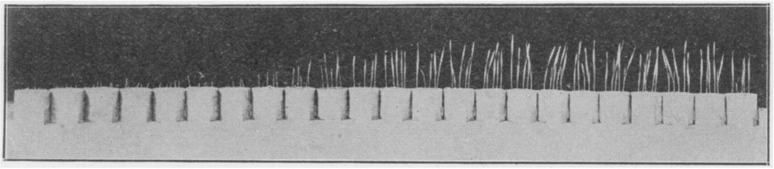

FIG. 18.—Zinc sulfate series in soil. Sept. 19–25. 1905.

Unfortunately, the plate showing the condition of the plants at the end of the experiment—18 days growth—was spoiled. However, by referring to Table X and *fig. 20* which represents this later condition, it will be seen that there is acceleration in concentrations 5*n*/10000 to *n*/10000. In comparison with lead nitrate this acceleration is in weak solutions and is not nearly as well marked as in the $Pb(NO_3)_2$. The series in solution of $ZnSO_4$ (*figs. 19, 21*, and

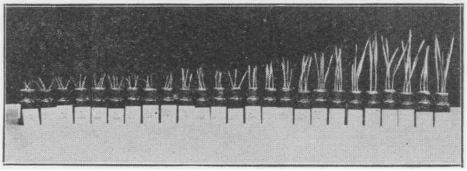

FIG. 19.—Zinc sulfate series in solution. Sept. 19–25. 1905.

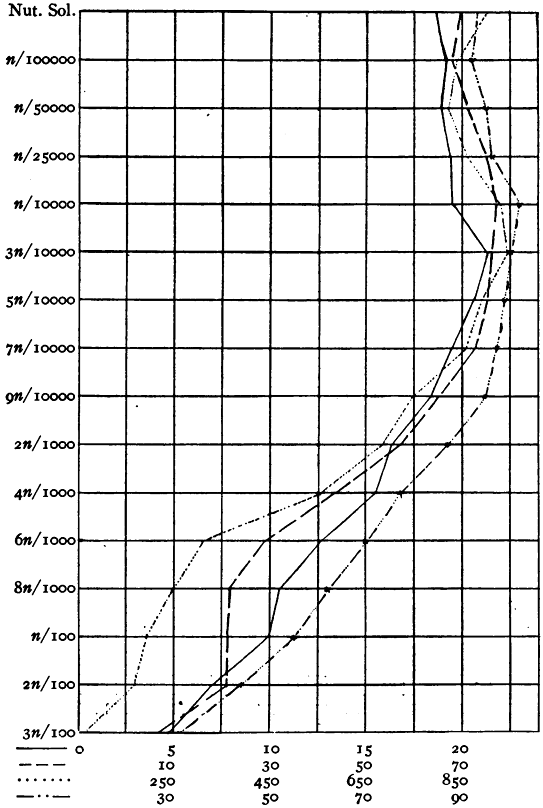

FIG. 20.—Zinc sulfate series in soil. Oct. 21–Nov. 18. 1905.

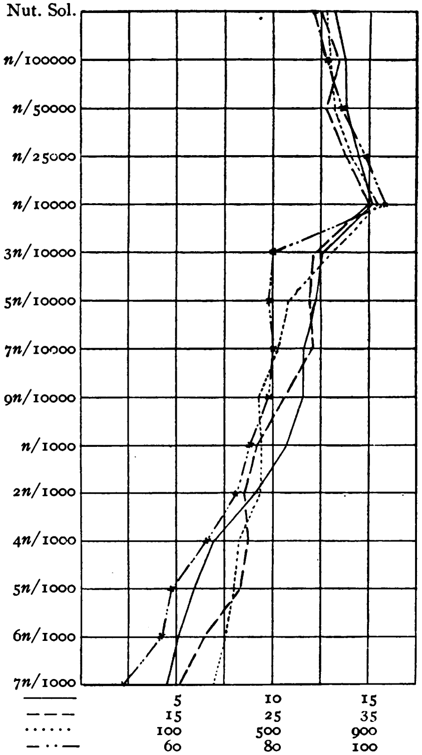

FIG. 21.—Zinc sulfate series in solution. Oct. 14–Nov. 14. 1905.

Table XI) does not show acceleration. It was thought that this was due to too strong solutions, hence the experiment was twice repeated with the concentrations as dilute as *n*/100000, as is seen in Table XI and *fig. 21*, but no very decided acceleration was obtained. This is contrary to the results obtained by RICHARDS (**34**), who found that $ZnSO_4$ was a most powerful stimulant to growth in fungi. ONO (**32**) and RICHTER (**35**) also report very strong stimulation with zinc sulfate. These observations correspond more nearly to my results obtained with soil.

It is very interesting to note the relatively small reduction of toxicity by the quartz in $ZnSO_4$ as compared with silver nitrate.

TABLE X

$ZnSO_4$ SERIES IN SOIL. OCTOBER 21–NOVEMBER 18, 1905

	Nut. sol.	$\frac{n}{100000}$	$\frac{n}{50000}$	$\frac{n}{25000}$	$\frac{n}{10000}$	$\frac{3n}{10000}$	$\frac{5n}{10000}$	$\frac{7n}{10000}$
Average length of sprout, cm	18.76	19.28	18.86	19.56	19.60	21.42	20.60	19.50
Total transpiration, gm	70.00	67.90	71.20	75.50	76.80	76.80	75.20	72.50
Total green weight, mg	905	847	810	857	929	949	890	890
Total dry weight, mg	94	92	95	96	102	100	99	97

	$\frac{9n}{10000}$	$\frac{2n}{1000}$	$\frac{4n}{1000}$	$\frac{6n}{1000}$	$\frac{8n}{1000}$	$\frac{n}{100}$	$\frac{2n}{100}$	$\frac{3n}{100}$
Average length of sprout, cm	18.28	16.20	15.42	12.72	10.30	10.12	7.14	4.9
Total transpiration, gm	64.60	56.90	43.80	29.20	21.90	21.40	21.	6.7
Total green weight, mg	748	677	601	310	250	196	169	76
Total dry weight, mg	96	87	77	70	62	55	44	31

TABLE XI

$ZnSO_4$ SERIES IN SOLUTION. OCTOBER 14–NOVEMBER 14, 1905

	Nut. sol.	$\frac{n}{100000}$	$\frac{n}{50000}$	$\frac{n}{25000}$	$\frac{n}{10000}$	$\frac{3n}{10000}$	$\frac{5n}{10000}$	$\frac{7n}{10000}$
Average length of sprout, cm	13.20	13.85	13.83	14.70	15.25	12.77	12.20	11.45
Total transpiration, gm	30.80	32.70	30.50	32.30	35.90	29.40	29.20	29.70
Total green weight, mg	717	740	746	782	948	730	567	527
Total dry weight, mg	89	91	94	100	104	80	79	80

	$\frac{9n}{10000}$	$\frac{n}{1000}$	$\frac{2n}{1000}$	$\frac{4n}{1000}$	$\frac{5n}{1000}$	$\frac{6n}{1000}$	$\frac{7n}{1000}$
Average length of sprout, cm	11.47	10.57	9.10	6.9	5.97	5.02	4.57
Total transpiration, gm	26.30	23.80	21.80	22.40	21.80	18.60	15.40
Total green weight, mg	445	443	447	369	354	315	307
Total dry weight, mg	78	77	77	66	59	57	47

IRON NITRATE

It was found impracticable to grow plants in the nutrient solution with which the experimentation was begun on account of precipitation of one or more of the salts by such reagents as $AgNO_3$, $Pb(NO_3)_2$, etc. Hence it was decided to grow them in distilled water, with no other element present than the poison. In order to test whether results obtained by both methods were comparable, two series, one in water, the other in nutrient media, to each of which the poison had been added in the same proportions, were set up side by side. The experimentation with $Fe_2(NO_3)_6$ proved that water grows the plants as well as does the nutrient solution during the time of the experiment. The curve of maximum growth is as great and comes at the same concentration with both. The killing concentrations also coincide.

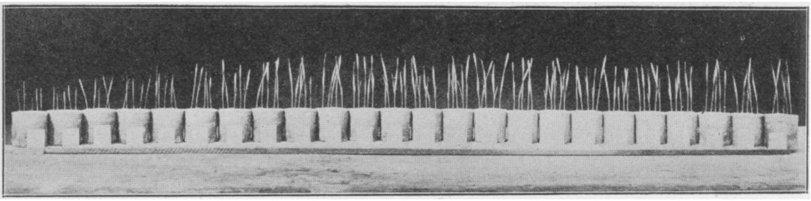

FIG. 22.—Iron nitrate series in soil. Sept. 15–21. 1905.

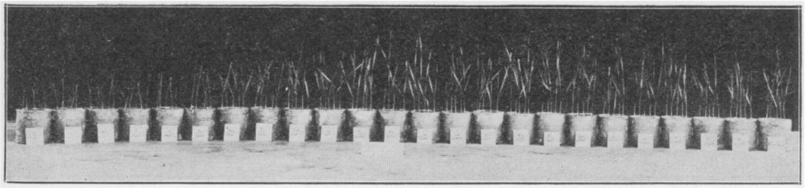

FIG. 23.—Iron nitrate series in soil. Sept. 15–27. 1905.

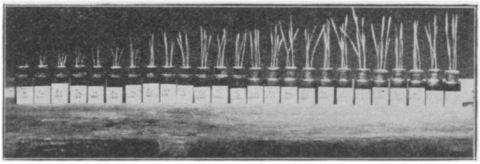

FIG. 24.—Iron nitrate series in solution. Sept. 15–21. 1905.

The greatest growth in solution cultures is at $n/2500$ to $n/7500$, while in soil cultures it occurs at $7n/1000$ to $3n/1000$. Hence there is a considerable reduction of stimulating effect caused by the presence of the quartz. Again the killing strength in solution is about $n/100$, while in soil it is from $6n/100$ to $4n/100$.

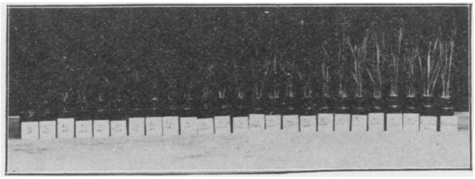

FIG. 25.—Iron nitrate series in solution. Sept. 15–27. 1905.

In comparison with $ZnSO_4$ and $AgNO_3$ iron is a weak poison. And it is interesting to note that there is not nearly as great an absorption of the poisonous elements in the latter as in the former. *Fig. 22* shows the $Fe_2(NO_3)_6$ soil series after growing five days. It will be noticed that some elongation has taken place in the culture farthest to the left, which is $n/10$. Further,

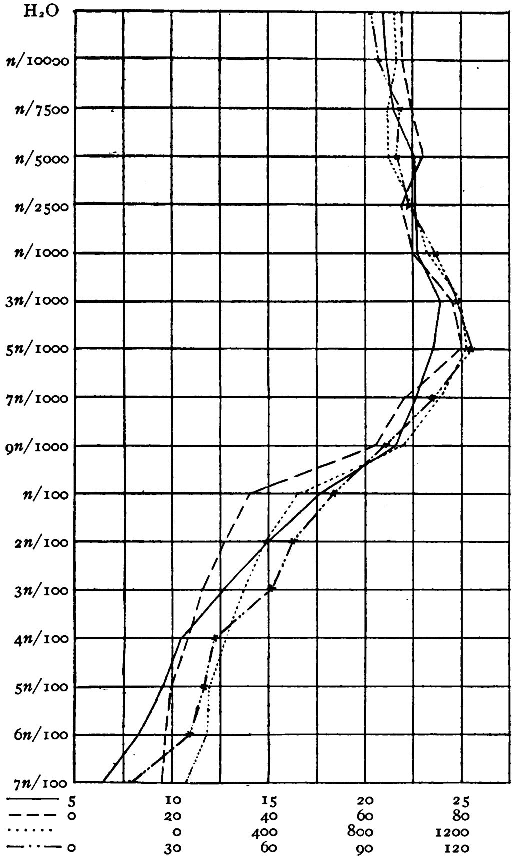

FIG. 26.—Iron nitrate series in soil with nutritive solution. Oct. 14–Nov. 8. 1905.

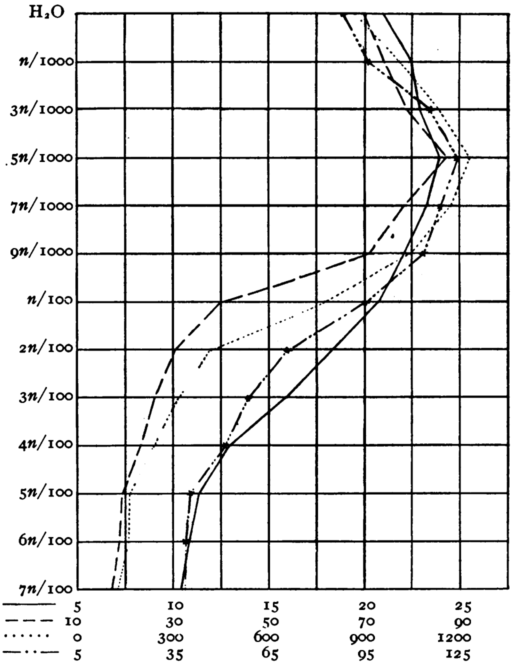

FIG. 27.—Iron nitrate series in soil without nutritive solution. Oct. 29–Nov. 24. 1905.

it is also clear, that no very marked stimulation above control, at extreme right, is perceptible. In *fig. 23*, which is the same series photographed when twelve days old, plants in pots from $n/10$ to $5n/100$ are dead, and the region of active stimulation is quite evident, lying at $9n/1000$ to $3n/1000$. In *figs. 24, 25* the same thing is illustrated for the water cultures with $Fe_2(NO_3)_6$ at the same ages as in *figs. 22, 23*. Tables XII and XIII give comparative results with and without nutrient media in the soil. The same is graphically shown in curves *figs. 26, 27*.

TABLE XII

$Fe_2(NO_3)_6$ SERIES IN SOIL WITH NUTRIENT SOLUTION. OCTOBER 14–NOVEMBER 8, 1905

	Nut. sol.	$\frac{n}{10000}$	$\frac{n}{7500}$	$\frac{n}{5000}$	$\frac{n}{2500}$	$\frac{n}{1000}$	$\frac{3n}{1000}$	$\frac{5n}{1000}$	$\frac{7n}{1000}$
Av. length of sprout, cm..	21.10	21.16	21.52	22.62	22.60	23.5	23.9	23.5	22.7
Total transpiration, gm...	67.6	68.8	70.7	72.8	68.6	70.5	78.7	80.9	68.6
Total green weight, mg...	945	992	905	914	1019	1019	1202	1217	1098
Total dry weight, mg.....	91	95	98	99	101	112	118	123	110

	$\frac{9n}{1000}$	$\frac{n}{100}$	$\frac{2n}{100}$	$\frac{3n}{100}$	$\frac{4n}{100}$	$\frac{5n}{100}$	$\frac{6n}{100}$	$\frac{7n}{100}$
Av. length of sprout, cm..........	21.6	17.8	12.7	12.7	10.4	9.5	8.3	6.4
Total transpiration, gm...........	65.7	36.0	28.4	26.1	23.1	19.0	18.3	18.1
Total green weight, mg...........	987	520	391	310	223	145	135	64
Total dry weight, mg.............	99	80	67	65	43	41	36	17

TABLE XIII

$Fe_2(NO_3)_6$ SERIES IN SOIL WITHOUT NUTRIENT SOLUTION. OCTOBER 29–NOVEMBER 24, 1905

	H_2O	$\frac{n}{1000}$	$\frac{3n}{1000}$	$\frac{5n}{1000}$	$\frac{7n}{1000}$	$\frac{9n}{1000}$	$\frac{n}{100}$	$\frac{2n}{100}$	$\frac{3n}{100}$	$\frac{4n}{100}$	$\frac{5n}{100}$	$\frac{6n}{100}$	$\frac{7n}{100}$
Av. length of sprout, cm..	21.98	22.60	22.84	23.92	23.12	22.04	20.96	18.44	15.90	12.90	11.36	10.94	10.38
Total transpiration, gm...	70.8	72.2	77.0	88.5	77.3	70.2	40.6	30.8	26.8	23.2	18.6	17.0	17.
Total green weight, mg...	855	1080	1180	1230	1183	1133	775	425	319	245	165	159	133
Total dry weight, mg.....	85	110	115	122	119	114	95	70	58	52	40	38	38

TABLE XIV

$Fe_2(NO_3)_6$ SERIES IN SOLUTION WITH NUTRIENT SOLUTION. OCTOBER 14–NOVEMBER 1, 1905

	Nut. Sol.	$\frac{n}{7500}$	$\frac{n}{2500}$	$\frac{3n}{1000}$	$\frac{4n}{1000}$	$\frac{7n}{1000}$	$\frac{8n}{1000}$	$\frac{n}{100}$	$\frac{3n}{100}$	$\frac{5n}{100}$
Av. length of sprout, cm.....	21.5	24.5	26.1	25.0	22.4	20.9	19.1	16.5	14.1	12.4
Total transpiration, gm.....	30.6	33.7	37.2	35.6	33.3	31.5	25.8	22.6	21.8	19.6
Total green weight, mg.....	1170	1500	1657	1380	1040	665	468	396	395	368
Total dry weight, mg.......	109	120	126	112	102	94	81	73	71	70

IRON CHLORID

Experiments with Fe_2Cl_6 were carried out in order to compare with $Fe_2(NO_3)_6$. It was found that plants die in the same concentration, and growth is accelerated in equal proportion by the same concentrations in either solution, as is shown in the Table XV.

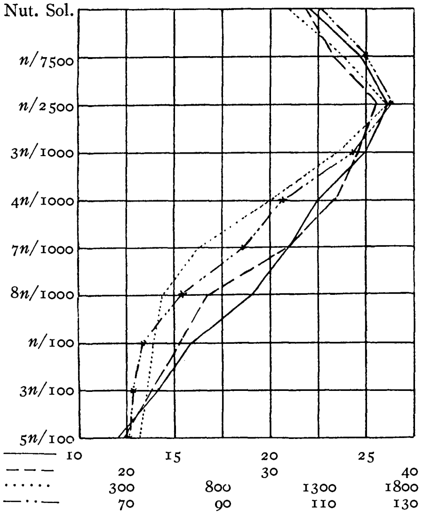

FIG. 28.—Iron nitrate series in nutritive solution. Oct. 14–Nov. 1. 1905.

TABLE XV

Fe_2Cl_6 SERIES IN SOIL. NOVEMBER 12–DECEMBER 12, 1905

	H_2O	$\frac{n}{1000}$	$\frac{2n}{1000}$	$\frac{3n}{1000}$	$\frac{4n}{1000}$	$\frac{6n}{1000}$	$\frac{7n}{1000}$	$\frac{8n}{1000}$	$\frac{9n}{1000}$	$\frac{n}{100}$	$\frac{2n}{100}$	$\frac{3n}{100}$	$\frac{4n}{100}$
Av. length of sprout, cm.	19.32	19.38	21.80	19.64	16.60	13.38	10.22	9.86	9.68	9.06	6.60	4.98	2.16
Total transpiration, gm.	85.30	75.80	78.10	62.9	41.10	36.40	27.70	29.20	29.10	29.10	30.70	24.90	24.10
Total green weight, mg.	787	845	835	652	490	450	235	205	188	119	40	35	26
Total dry weight, mg..	130	154	140	107	90	87	45	40	34	26	15	12	6

NICKEL NITRATE

In nickel nitrate cultures is shown the most remarkable reduction of toxicity by the introduction of the quartz. Thus, in soil, plants die in concentrations $7n/2000$ to $6n/4000$, while in solution death occurs at $n/2000$ to $n/4000$. Stimulation effects are most marked in soil at $n/2000$ to $n/10000$, but in solution at $4n/10,000,000$ Tables

XVI and XVIII are the averages of three sets of experiments, the results of which are plotted in *figs. 29, 30.*

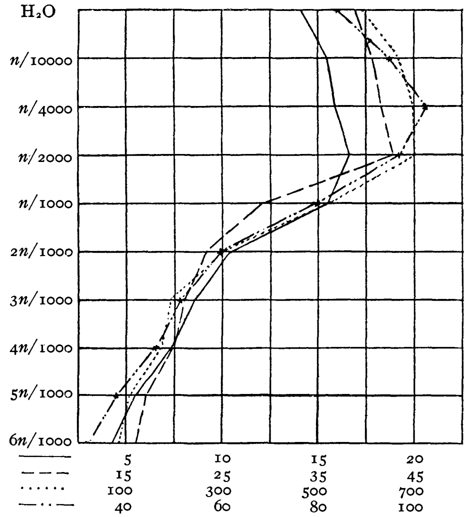

FIG. 29.—Nickel nitrate series in soil. Mar. 17–Apr. 2. 1906.

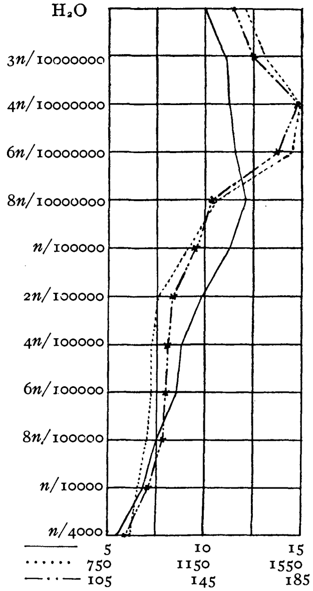

FIG. 30.—Nickel nitrate series in solution. Mar. 29–Apr. 8. 1906.

TABLE XVI

$Ni(NO_3)_2$ SERIES IN SOIL. MARCH 17–APRIL 2, 1906

	H_2O	$\frac{n}{10000}$	$\frac{n}{4000}$	$\frac{n}{2000}$	$\frac{n}{1000}$	$\frac{2n}{1000}$	$\frac{3n}{1000}$	$\frac{4n}{1000}$	$\frac{5n}{1000}$	$\frac{6n}{1000}$	$\frac{7n}{1000}$
Av. length of sprout, cm...	14.16	15.40	15.94	16.50	15.20	10.30	8.50	7.30	5.40	4.30	Dead
Total transpiration, gm....	39.3	41.7	42.8	43.6	29.4	23.1	21.0	19.7	17.4	17.3	
Total green weight, mg....	574	685	696	668	518	290	185	169	103	91	
Total dry weight, mg......	84	95	102	96	82	59	49	40	40	30	

TABLE XVII

$Ni(NO_3)_2$ SERIES IN SOLUTION. MARCH 29–APRIL 8, 1906

	H_2O	$\frac{2n}{10000000}$	$\frac{4n}{10000000}$	$\frac{6n}{10000000}$	$\frac{8n}{10000000}$	$\frac{n}{100000}$
Av. length of sprout, cm.......	11.35	11.36	11.40	11.55	11.20	9.95
Total green weight, mg........	1310	1345	1535	1490	1180	1060
Total dry weight, mg..........	154	160	185	170	146	140

TABLE XVII.—*Continued*

	$\frac{2n}{100000}$	$\frac{4n}{100000}$	$\frac{6n}{100000}$	$\frac{8n}{100000}$	$\frac{n}{10000}$	$\frac{n}{4000}$
Av. length of sprout, cm.......	8.66	8.21	7.40	7.38	6.83	5.50
Total green weight, mg........	915	885	860	859	828	820
Total dry weight, mg..........	129	128	126	126	122	113

PHENOL

In the phenol series death occurs at very nearly the same concentration in soil and in solution, viz., $2n/100$ to $n/100$. There is a very slight indication of reduction of the acceleration strength by the presence of quartz; thus, in soil the greatest growth occurs at $6n/10000$, in solution at $4n/10000$.

TABLE XVIII

PHENOL SERIES IN SOIL. MARCH 17–APRIL 2. 1906

	H_2O	$\frac{n}{10000}$	$\frac{2n}{10000}$	$\frac{4n}{10000}$	$\frac{6n}{10000}$	$\frac{8n}{10000}$	$\frac{n}{1000}$
Av. length of sprout, cm...	12.52	13.94	13.56	14.50	13.98	13.70	14.48
Total transpiration, gm....	39.1	43	44.9	44.9	48	43.7	40.1
Total green weight, mg....	523	560	590	650	668	653	611
Total dry weight, mg......	87	85	90	108	115	107	101

	$\frac{2n}{1000}$	$\frac{4n}{1000}$	$\frac{6n}{1000}$	$\frac{8n}{1000}$	$\frac{n}{100}$	$\frac{2n}{100}$
Av. length of sprout, cm.............	14.20	14.02	13.68	12.84	11.66	3.26
Total transpiration, gm..............	37.1	38.8	33.3	29.0	20.4	12.5
Total green weight, mg..............	523	518	488	470	403	68
Total dry weight, mg................	95	85	77	72	54	17

TABLE XIX

PHENOL SERIES IN SOLUTION. MARCH 8–22. 1906

	H_2O	$\frac{n}{10000}$	$\frac{2n}{10000}$	$\frac{4n}{10000}$	$\frac{6n}{10000}$	$\frac{8n}{10000}$	$\frac{n}{1000}$
Av. length of sprout, cm...	13.31	13.30	13.73	15.38	13.73	11.26	10.35
Total transpiration, gm....							
Total green weight, mg....	1148	1153	1146	1191	1053	965	884
Total dry weight, mg......	140	142	146	148	140	131	122

	$\frac{2n}{1000}$	$\frac{4n}{1000}$	$\frac{6n}{1000}$	$\frac{8n}{1000}$	$\frac{n}{100}$	$\frac{2n}{100}$
Av. length of sprout, cm.............	8.81	8.20	7.71	6.23	5.23	4.10
Total transpiration, gm..............						
Total green weight, mg..............	823	701	640	575	521	440
Total dry weight, mg................	114	103	101	83	82	70

These results are shown graphically in *figs. 31, 32.*

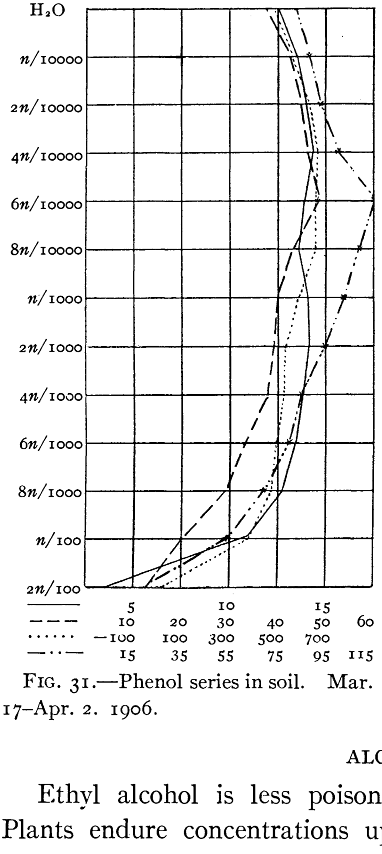

FIG. 31.—Phenol series in soil. Mar. 17–Apr. 2. 1906.

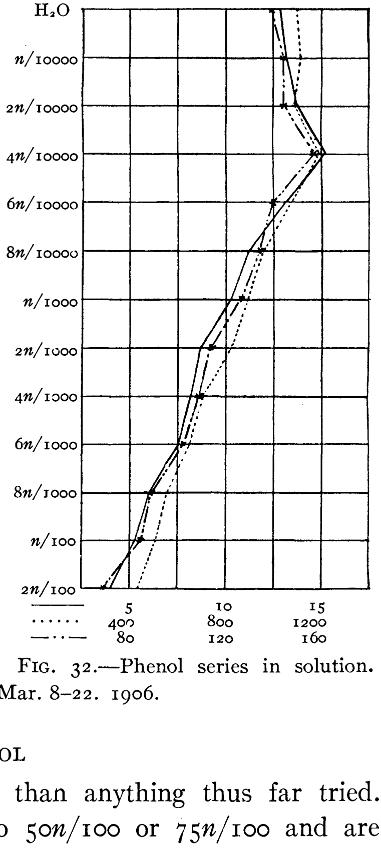

FIG. 32.—Phenol series in solution. Mar. 8–22. 1906.

ALCOHOL

Ethyl alcohol is less poisonous than anything thus far tried. Plants endure concentrations up to 50*n*/100 or 75*n*/100 and are most actively stimulated by 75*n*/1000 to 25*n*/1000 in both solution and soil. In the case of alcohol and phenol, therefore, the absorption of poison by quartz is practically a negligible quantity. Tables XX, XXI, and *figs. 33, 34* show acceleration in soil at 75*n*/1000 and in solution at 50*n*/1000.

TABLE XX

ALCOHOL SERIES IN SOIL. MARCH 2–22. 1906.

	H_2O	$\frac{10n}{1000}$	$\frac{25n}{1000}$	$\frac{50n}{1000}$	$\frac{75n}{1000}$	$\frac{10n}{100}$	$\frac{25n}{100}$	$\frac{50n}{100}$	$\frac{75n}{100}$	*n*
Av. length of sprout, cm......	19.02	18.92	19.34	19.02	20.64	18.64	15.46	11.14	6.16	3.44
Total transpiration, gm	38.80	37.80	37.90	38.70	40.30	31.30	24.10	14.50	13.70	6.90
Total green weight, mg	690	640	649	661	765	611	570	310	80	50
Total dry weight, mg	96	92	94	100	115	91	80	57	40	20

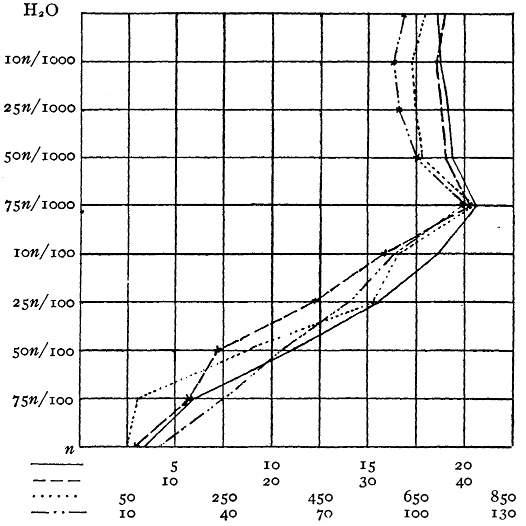

FIG. 33.—Alcohol series in soil. Mar. 2–22. 1906.

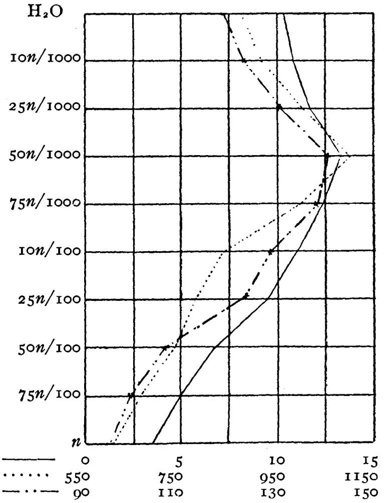

FIG. 34.—Alcohol series in solution. Mar. 2–22. 1906.

TABLE XXI

ALCOHOL SERIES IN SOLUTION. MARCH 2–22. 1906

	H₂O	$\frac{10n}{1000}$	$\frac{25n}{1000}$	$\frac{50n}{1000}$	$\frac{75n}{1000}$	$\frac{10n}{100}$	$\frac{25n}{100}$	$\frac{50n}{100}$	$\frac{75n}{100}$	n
Av. length of sprout, cm.....	10.30	10.85	11.83	13.35	12.23	10.96	9.43	6.66	4.81	3.40
Total transpiration, gm.....										
Total green weight, mg......	877	910	1012	1109	997	831	778	729	653	513
Total dry weight, mg.......	115	122	130	140	138	126	127	100	97	95

SUMMARY OF RESULTS

Table XXII shows the concentrations in which growth in quartz soil and in solution is stimulated and inhibited. From this it will be seen that in soil, nickel is by far the most toxic substance tried, being nearly five times as poisonous as zinc, silver, copper, six to eight times as poisonous as iron, and forty to one hundred times as poisonous as alcohol. On the other hand silver in solution cultures is more poisonous than nickel, zinc, or copper, the ratios being as 1 to 5, 7, and 10 respectively; while with iron, lead, and alcohol the ratios are 1 to 100, 400, and 7500.

It does not follow, therefore, that because a salt is highly toxic in solution it is equally so in soil; nor that one which holds a rela-

TABLE XXII

SUMMATION OF KILLING AND STIMULATING CONCENTRATIONS SELECTED FROM FOREGOING DATA

POISON	SOIL CULTURES		SOLUTION CULTURES	
	Growth inhibited	Growth stimulated	Growth inhibited	Growth stimulated
$Ni(NO_3)_2$	$\frac{7n \text{ to } 6n}{1000}$	$\frac{5n \text{ to } n}{10000}$	$\frac{50n \text{ to } 25n}{100000}$	$\frac{4n \text{ to } 2n}{10000000}$
$ZnSO_4$	$\frac{30n \text{ to } 10n}{1000}$	$\frac{3n \text{ to } n}{10000}$	$\frac{70n \text{ to } 60n}{100000}$	None
$AgNO_3$	$\frac{30n \text{ to } 10n}{1000}$	$\frac{90n \text{ to } 10n}{10000}$	$\frac{10n \text{ to } 9n}{100000}$	$\frac{20n \text{ to } 10n}{10000000}$
$CuSO_4$	$\frac{30n \text{ to } 10n}{1000}$	$\frac{10n \text{ to } 4n}{10000}$	$\frac{100n \text{ to } 50n}{100000}$	None
$Fe_2(NO_3)_6$	$\frac{60n \text{ to } 40n}{1000}$	$\frac{90n \text{ to } 30n}{10000}$	$\frac{1000n \text{ to } 900n}{100000}$	$\frac{4000n \text{ to } 2000n}{10000000}$
Fe_2Cl_6	$\frac{60n \text{ to } 40n}{1000}$	$\frac{90n \text{ to } 20n}{10000}$	$\frac{1000n \text{ to } 800n}{100000}$	$\frac{4000n \text{ to } 2000n}{10000000}$
$Pb(NO_3)_2$	$\frac{50n \text{ to } 30n}{1000}$	$\frac{90n \text{ to } 40n}{10000}$	$\frac{4000n \text{ to } 2000n}{100000}$	$\frac{20000n \text{ to } 10000n}{10000000}$
Phenol	$\frac{20n \text{ to } 10n}{1000}$	$\frac{8n \text{ to } 4n}{10000}$	$\frac{2000n \text{ to } 1000n}{100000}$	$\frac{8000n \text{ to } 4000n}{10000000}$
Alcohol	$\frac{750n \text{ to } 250n}{1000}$	$\frac{750n \text{ to } 250n}{10000}$	$\frac{75000n \text{ to } 25000n}{100000}$	$\frac{75000n \text{ to } 25000n}{10000000}$

tively high position in the toxic table in soil should occupy the same relative position in solution cultures. Hence the assumption upon which HARTER (**18**) worked is not verified by my results.

The reduction of toxic effect (seen by comparing columns 1 and 3, Table XXII) is most marked in Ni, less in Ag, Zn, Cu, Fe, and Pb, in the order given, and no reduction whatever is apparent in phenol or alcohol.

Stimulation to growth takes place more markedly in soil than in solution, because in soil every test gave accelerating effects, while in solution cultures two failed to give such results. Stimulation in soil is always at a much higher concentration than stimulation in solution except in the case of the organic poisons tried, phenol and alcohol, where the presence of quartz does not reduce the toxicity.

Conclusions

In conclusion I wish to point out what seem to me the most salient features of this research.

1. While considerable work has been done on toxicity, none has shown the definite effects of a poison in pure soil, for, as I have

elsewhere stated, such experiments have been made with garden loam and are unreliable because of the multiplicity of inorganic and organic substances with which the introduced poison may react. My results show that the introduction of pure quartz flour into a toxic solution, in such proportion as to form an ordinary moist soil, reduces the toxicity of the solution in a marked degree. But whether this reduction is due to adsorption, as TRUE and OGLEVEE would have it, or to a reduced freedom of movement of the solute particles, that is, a reduction of diffusion tension, as DANDENO suggests, or to some chemical changes enhanced by the quartz is yet an open question.

2. Of the limited number of poisons tried, all gave stimulation results in quartz, and all but two—$ZnSO_4$ and $CuSO_4$—in solution cultures. It is not beyond probability that these two, in proper concentration, might also be found to be stimulating.

3. The more dilute the fatal dose in solution, the more the toxic effect is reduced by the introduction of quartz. Hence the range of concentrations, both fatal and accelerating, is much greater in solution than in soil cultures.

Finally, I wish to acknowledge the friendly cooperation of all members of the botanical staff of the university, and especially the stimulating suggestions of Professor CHARLES R. BARNES and Dr. B. E. LIVINGSTON.

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